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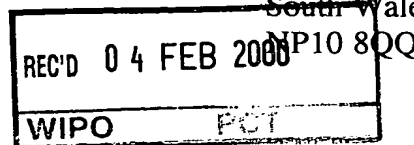
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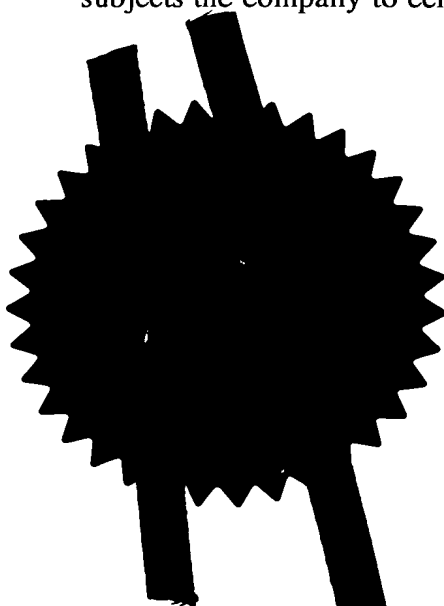
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Form 1/77
Patents Act 1977

1 Title of invention

1 Please give the title of the invention

IMPROVEMENTS IN AND RELATING TO APPARATUS AND METHODS FOR MATERIALS INVESTIGATION

2 Applicant's details

☐ First or only applicant

2a If you are applying as a corporate body please give:

Corporate name
BRITISH NUCLEAR FUELS PLC

Country (and State of incorporation, if appropriate)

UNITED KINGDOM

2b If you are applying as an individual or one of a partnership please give in full:

Surname

Forenames

2c In all cases, please give the following details:

Address
RISLEY
WARRINGTON
CHESHIRE

UK postcode WA3 6AS
(if applicable)

Country   UNITED KINGDOM

ADP number
(if known)   350 108 002

2d, 2e and 2f:
If there are further applicants please provide details on a separate sheet of paper.

☐ **Second applicant (if any)**

2d If you are applying as a corporate body please give:

Corporate name

Country *(and State of incorporation, if appropriate)*

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Forenames

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3
An address for service in the United Kingdom must be supplied.
Please mark correct box

3 Address for service details

3a Have you appointed an agent to deal with your application?

Yes ☒   No ☐ ➡ *go to 3b*

⬇

Please give details below

Agent's name
URQUHART-DYKES & LORD
Agent's address
TOWER HOUSE
MERRION WAY
LEEDS

Postcode   LS2 8PA

Agent's ADP   1644004-
number

3b:
If you have appointed an agent, all correspondence concerning your application will be sent to the agent's United Kingdom address.

3b If you have not appointed an agent please give a name and address in the United Kingdom to which all correspondence will be sent:

Name

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4 Reference number

4 Agent's or applicant's reference number *(if applicable)*   ANP/P17454

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A 5 Claiming an earlier application date

5 Are you claiming that this application be treated as having been filed on the date of filing of an earlier application?

Please mark correct box   Yes ☐   No ☒ ➡ *go to 6*

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☐ filing date

(day   month   year)

☐ and the Section of the Patents Act 1977 under which you are claiming:

Please mark correct box   15(4) (Divisional) ☐   8(3) ☐   12(6) ☐   37(4) ☐

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6
If you are declaring priority from a PCT Application please enter 'PCT' as the country and enter the country code (for example, GB) as part of the application number.

Please give the date in all number format, for example, 31/05/90 for 31 May 1990.

6 If you are declaring priority from previous application(s), please give:

Country of filing	Priority application number *(if known)*	Filing date *(day,month,year)*

7

The answer must be 'No' if:
- *any applicant is not an inventor*
- *there is an inventor who is not an applicant, or*
- *any applicant is a corporate body.*

7 Inventorship

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8

Please supply duplicates of claim(s), abstract, description and drawing(s).

8 Checklist

8a   Please fill in the number of sheets for each of the following types of document contained in this application.

Continuation sheets for this Patents Form 1/77   ☐

Claim(s) ☐   Description | 21 |

Abstract ☐   Drawing(s) | 2 |

8b   Which of the following documents also accompanies the application?

Priority documents *(please state how many)*   ☐

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Patents Form 7/77 - Statement of Inventorship and Right to Grant *(please state how many)*   ☐

Patents Form 9/77 - Preliminary Examination/Search   ☐

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9

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IMPROVEMENTS IN AND RELATING TO APPARATUS
AND METHODS FOR MATERIALS INVESTIGATION

This invention is concerned with improvements in and relating to apparatus and methods for materials investigations. The invention is particularly, but not exclusively, concerned with investigating gamma ray emissions from materials. The invention is still more particularly, but not exclusively, concerned with correction techniques including the provision of more suitable transmission sources and an improved correction technique.

In a variety of situations it is necessary to investigate emissions from radioactive sources in or on materials to form a basis for a variety of subsequent decisions, actions or further considerations. The investigations of the samples may relate directly to the emission, for instance the emission source, or indirectly, for instance the consideration of associated non-emitters or emitters which are not directly measurable. The emissions of interest are in particular gamma ray emissions, but other emission forms may be considered additionally or alternatively.

Emission investigation is particularly important in waste evaluation cases. For a given waste sample it is desirable to be able to determine a variety of unknowns. The unknowns may include, but are not limited to, one or more of the level, type, constituents, nature and distribution of the emissions, emission sources, associated materials or associated factors.

As well as simply using the results obtained from the detectors, emission count rates for the radioactive materials in the sample under consideration, it is known to investigate to an extent the effects of the all the material in a sample, through their effect on the transmission of external

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emissions from an applied source through the sample to the detectors.

The applicant has determined that such simple sources are not suitable for transmission based investigation and correction at the full variety of energies and with the full variety of materials. As a consequence the effectiveness of the correction technique based on these investigations is impaired.

The present invention seeks to provide a more widely accurate transmission based correction, which is also simple and easy to use across a full spread of situations which are encountered in practice.

In addition the existing transmission based correction techniques only go part way to account for the variables which affect the detected counts for the sources of the sample itself and as a result the correction technique is not fully effective.

The present invention has amongst its aims the provision of a more accurate and thorough correction technique based on transmission correction and the manner in which it is employed.

According to a first aspect of the invention we provide a method of investigating radioactive sources in a sample, the method comprising detecting a portion of the emissions arising from the sample, and further comprising the provision of a radioactive generator, passing at least a portion of the emissions of the generator into the sample, detecting at least a portion of the emissions from the generator leaving the sample, the radioactive generator emissions being of at least a plurality of emission energies and at least two of those energies being detected.

Preferably the method further provides that the detected portion of the source emissions relate to a detected

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level for the sources in a sample, the detected level being corrected according to a correction method to give a corrected level for the sources in a sample, the process being repeated for one or more other samples.

Preferably the correction method employs measured transmission coefficients in determining the correction. The measured transmission coefficients, for one or more of the energies, most preferably all, may be provided according to the equation :-

$$\text{Trans. Coeff.} = \frac{R}{R_o}$$

where R is the rate of detected photons with the sample in place, R_o is the rate of photons which would be detected without the sample in place.

Preferably the density determined is used as a factor in the correction method. The density used in the correction method may be an averaged density from the determinations or a weighted average density from the determinations.

For correction of source emission energies corresponding to a generator energy preferably the measurement based correction factor is used. For correction of source emission energies not corresponding to a generator energy preferably the correction factor is based on the extrapolation of the correction factors based on the measurements.

The generator is preferably a single isotope. Preferably the emission energies extend across a substantial portion of the range of energies emitted from the sample. A substantial portion may be 50%, preferably 75%, more preferably 90% and ideally 100% of the sample energies range. The generator most preferably of all emits energies encompassing the range of energies emitted by the sample.

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^{152}Eu is a particularly preferred generator. Preferably at least 5 energies from the source are detected and used, more preferably at least 8 energies are detected and used.

Preferably the portion of generator emissions detected have passed through the sample. Preferably the generator is provided on the opposing side of the sample to the detectors, most preferably in direct opposition.

One or more of the detectors for the sources may be used for detecting the generator emissions and/or vice-versa.

According to a second aspect of the invention we provide apparatus for investigating radioactive sources in a sample, the apparatus comprising :

one or more detectors for emissions from the sources, the detectors generating signals indicative of the emissions detected;

an investigating location into which the sample is introduced;

signal processing means for relating the detector signals to one or more characteristics of the sources;

a radioactive emission generator separate from the sample; and

one or more detectors for emissions from the radioactive generator leaving the sample;

wherein the radioactive generator emissions are of at least a plurality of energies and a least two of the plurality of energies are detected.

The source detectors and the generator detectors may be one and the same in the case of one or more or all of the detectors.

The second aspect of the invention may include any of the features, options and possibilities set out on the first aspect of the invention, including apparatus suitable for the implementation of the method steps detailed therein.

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According to a third aspect of the invention we provide a method of investigating radioactive sources in a sample, the method comprising detecting a portion of the emissions arising from the sample at an energy, the detected portion relating to a detected level, the detected level being corrected according to a correction method to give a corrected level, at that energy, the correction method including :-

the provision of a multi-energy emission generator, passing at least a portion of the emissions of the generator into the sample, detecting at least a portion of the emissions from the generator leaving the sample, and determining a value for a first relationship between the two portions;

calculating a value for a relationship of equivalent type to the first, the calculation being based on functions of an element's absorption of emissions and the amount of that element potentially encountered by emissions, for one or more elements;

adjusting one or more variables in the calculated relationship to reduce the difference between the value of the determined relationship and the value of the calculated relationship for the sample at a plurality of the energies of emissions from the generator; and

obtaining the values of the calculated relationship functions from the reduction and calculating the calculated relationship from those factors at the sample source emission energy requiring correction and correcting the detected level using those values.

Preferably the generator emissions are of at least two emission energies and at least two of those energies being detected.

The generator is preferably a single isotope.
Preferably the emission energies extend across a substantial

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portion of the range of energies emitted from the sample. A
substantial portion may be 50%, preferably 75%, more
preferably 90% and ideally 100% of the sample energies range.
The generator most preferably of all, emits energies
encompassing the range of energies emitted by the sample.
Eu^{152} is a particularly preferred generator.

Preferably the portion of generator emissions detected
have passed through the sample. Preferably the generator is
provided on the opposing side of the sample to the detectors,
most preferably in direct opposition.

One or more of the detectors for the sources may be
used for detecting the generator emissions and/or vice-versa.

Preferably the first relationship employs measured
transmission coefficients, and ideally comprises measured
transmission coefficients. The measured transmission
coefficients, for one or more of the energies, most
preferably all, may be provided according to the equation :-

$$Trans.\ Coeff. = \frac{R}{R_o}$$

where R is the rate of detected photons with the sample
in place, R_o is the rate of photons which would be detected
without the sample in place.

Preferably the calculated relationship is based on
functions addressing one or more of the density, emission
path length in the sample and sample absorption of emissions.
Preferably the calculated relationship is based on functions
addressing one or both of the effect of the material forming
the sample over the emission path length in the sample and
the sample absorption of emissions.

The calculated relationship is preferably based on the
equation :-

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$$T_i = \exp\left(-\sum q_j \cdot \mu_{i,j} \right)$$

where T_i is the transmission coefficient at the energy i
under consideration; q_j is the effective material thickness
or the effect of the specified material forming the sample
over the specified emission path length through the sample,
for element j; $\mu_{i,j}$ is the mass absorption coefficient for
elements j at energy i. The sum including all of the
specified elements, j, included in the method.

Preferably the calculated relationship includes
contributions from two or more elements, and most preferably
three or more. The elements may be elements in the sample,
likely to be in the sample, unknown or not in the sample.

Most preferably the elements include at least one low
atomic mass element, preferably less than 10 and ideally less
than 5. Preferably the elements include at least one high
atomic mass element, preferably greater than 40 and ideally
greater than 50. Preferably the elements include at least
one intermediate atomic mass element, preferably between 10
and 50 and ideally between 10 and 40. Ideally at least one
element from each category is provided.

Preferably the adjusting of the factors varies one or
two of the factors only. Preferably only the effective
material thickness or the effect of the specified material
forming the sample over the specified emission path length
through the sample are varied, particularly where one factor
only is varied.

The reduction in the differences between the first
relationship value and calculated value may be undertaken so
as to reduce the overall difference between all of the first
relationship and calculated relationship values involved.
The reduction may be intended to minimise the difference.
The reduction process may be a minimisation of the sum of the
residuals.

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Preferably the method is repeated for one or more other samples, the one or more other samples may, with the sample, form a body of material under investigation.

For the correction of source emission energies corresponding to a generator emission energy, preferably the measurement based correction factor alone, i.e. the first relationship, is used.

According to a fourth aspect of the invention we provide apparatus for investigating radioactive sources in a sample, the apparatus comprising :

one or more detectors for emissions from the sources, the detectors generating signals indicative of the emissions detected;

an investigating location into which the sample is introduced;

signal processing means for relating the detector signals to a detected level for the sources;

processing means for correcting the detected level for the sources, according to a correction method, to give a corrected level;

a radioactive emission generator separate from the sample;

one or more detectors for emissions from the generator which leave the sample;

processing means for determining a first relationship, based on the portion of generator emissions entering the sample and the portion of generator emissions leaving the sample;

processing means for calculating a value for a relationship of equivalent type to the first, the calculation being based on functions of an element's absorption of emissions and the amount of that element potentially encountered by emissions, for one or more elements;

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processing means for adjusting one or more variables in the calculated relationship to reduce the difference between the value of the determined relationship and the value of the calculated relationship for the sample at a plurality of the energies of emissions from the generator; and

calculating means for obtaining the values of the calculated relationship functions from the reduction and calculating the calculated relationship from those factors at the sample source emission energy requiring correction and correcting the detected level using that value.

The processing means may be separate from one another or a common unit in one or more cases, including the calculating means.

The fourth aspect of the invention may include any of the features, options and possibilities set out on the third aspect of the invention, including apparatus suitable for the implementation of the method steps detailed therein.

The first and/or second and/or third and/or fourth aspects of the invention may further include any of the features, options, possibilities and steps set out below.

The sources may be singular or plural in disposition and/or type. The sources may be one or more isotopes of one or more elements. The sources may be alpha and/or beta and/or gamma emitters, but are preferably gamma emitters at least.

One or more sources of the same type and/or of different types may be present in the sample. The sources may be homogeneously distributed, or more usually, unevenly distributed. The size and/or shape and/or mass of a source may be different from the size and/or shape and/or mass of another source in the sample, be they of the same or different types.

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The sources may be investigated by detecting one or more of their emitting energies. Thus a characteristic energy of an isotope may be detected.

The sources may be investigated directly, for instance they contribute directly to the detected level, and/or the sources may be investigated indirectly, for instance they do not contribute directly to the detected level but are associated with sources which do.

The samples may be gaseous and/or liquid and/or solid. The samples may contain one or more non-emitting or non-source materials. The materials may include one or more of metals, such as iron, steel, aluminum; wood; glass; plastics, such as polythene, PVC; liquids, such as water.

The sample may be the whole or part of a body of material. The body of material may be free standing, but is preferably contained in a container. The sample may be a part of a body of material, including the part of the container associated with that part of the body of material.

The sample may be a segment or slice through a body of material. Preferably the segment is taken horizontally through the body of material. Preferably the segment has the same thickness throughout the body of material.

Other segments of the body of material may be investigated in subsequent repeats of the method.

The container preferably entirely encloses the body of material. The container may be of metal or of concrete or a combination of such materials. Drums are a particularly preferred container, such as right cylindrical drums.

The containers may be of one or more standard sizes. The height and/or diameter of the containers may be standard.

Preferably the containers introduced to the investigating location one at a time. The containers may be introduced by conveying along a surface, preferably a horizontal surface. The surface may include or be formed of a plurality of rollers. Preferably the container is removed

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from the investigating location in a manner equivalent to its introduction.

The investigating location is preferably provided in proximity to the emission detector or detectors. The investigating location may be provided in proximity to one or more radioactive sources. The sources are preferably intended to transmit radiation through the sample. Ideally the investigating location is provided between the detector(s) and the transmission source(s).

The sample, preferably the container for it, may be rotated at the investigating location. Preferably the rotation presents different portions of the sample in proximity to the detector(s) and/or transmission source(s). the rotation may be continuous or stepped. The rotation may be provided at between 5 and 25 rpm.

Preferably the sample and/or body of material and/or container are weighed, most preferably at the investigating location, for instance by the turntable used to rotate it.

The sample, preferably the container for it, may be raised and/or lowered at the investigating location. Preferably the rasing and/or lowering presents different portions of the sample to the detector(s) and/or transmission source(s). the raising and/or lower may be continuous or stepped. Preferably investigations are performed as the sample is lower and raised.

The sample may be rotated and/or lower and/or raised.

A single detector may be used. Preferably a plurality of detectors, for instance three, may be used.

The detectors may be of the high purity germanium type.

Preferably the detectors are collimated to restrict their field of view to the body of material of which the sample is the whole or a portion thereof. Where the sample is less than the whole of the body of material, preferably the detectors are collimated to restrict their field of view to the sample only. The sample is preferably a slice or

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segment of the whole. The segments may be of the same
thickness.

Preferably the detected level is obtained from a
passive counting stage. Preferably the transmission based
investigations are performed before and/or after the passive
count stage.

Preferably the transmission source(s) is provided in
opposition to the detector(s). Preferably the same number of
transmission sources are provided as there are detectors. It
is particularly preferred that the transmission source be
provided according to nature of the transmission source
detailed in the first and/or second aspect of this invention.

One or more surface dosimeters may be provided.
Preferably the surface dosimeters are configured to
investigate gamma emitting sources. Alpha and/or beta
emissions may alternatively or additionally considered.

Preferably the correction method is used in correcting
the detected level to the corrected level, for instance by
established subsequent techniques, such as those set out in
the Los Alamos primer, 2nd Edition, March 1991, ISBN0-16-
032724-5.

Various embodiments of the invention will now be
described, by way of example only, and with reference to the
accompanying drawings in which :-

Figure 1 illustrates schematically an instrument
suitable for implementing the present invention;

Figure 2 illustrates measured and fitted
transmission coefficients calculated according to one
embodiment of the invention for a drum containing a paper
matrix (density <0.1g.cm^{-3});

Figure 3 illustrates measured and fitted
transmission coefficients for a PVC matrix (density =
0.4g.cm^{-3}); and

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Figure 4 illustrates measured and fitted transmission coefficients for an iron matrix (density 1.5g.cm^{-3}).

The instrument illustrated in Figure 1 is suitable for investigating gamma emission sources in a variety of situations and materials. The system 1 is particularly designed to investigate waste samples presented in drums 3 to investigating location 5.

The drums considered may be in a variety of sizes, but the instrument is readily adapted to consider 100, 200 and 500 litre drums. Masses of waste, such as 40kg to 550kg, can readily be accommodated.

The drums 3 may be provided with a barcode which can be examined by a barcode reader on the system 1 so as to permanently assign results obtained to that drum 3.

The system 1 features a conveying table 7 formed of a large number of parallel rollers 9, onto which the drums are lowered. Cranes, forklift trucks and other lifting and manoeuvring means can be used to this end.

The conveying table 7 leads to the investigating location 5 and then onward out the other side to a dismounting location 11 from which the drums 3 are lifted. This set up allows the flow of samples for investigation through the system.

The drum 3 is supported at the investigating location 5 by a turntable 13 which again is formed by a number of parallel rollers 15 mounted on a moveable frame 17. The frame 17 can be rotated about a vertical axis, using a motor (not shown), so as to rotate the drum 3 about its longitudinal axis at the investigating location 5. A rotational rate of 12 rpm is preferred, but stepped rotation can be used. The frame 17 can also be provided with the option of being raised and lowered relative to the level of the surrounding conveying table 7, using electrical drives,

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hydraulics or other systems (not shown), so as to adjust the vertical positioning of the drum 3 within the investigating location 5. The lowering and rotating motions may be applied simultaneously.

The turntable 13 and frame 17 are configured to weigh the drum 3 whilst it is on the turntable 13.

On either side of the investigating location 5 are investigating assemblies 19, 21. In general one of these assemblies 19 acts as the, optional, transmission side and the other 21 as the detecting/receiving side for the investigations.

The detecting/receiving side 21 provides one or more detectors 23 for the emission type under consideration. The detectors 23 are collimated using shields 25 to give a restricted field of view into the investigating location 5 for each detector 23. Through the use of variable aperture collimators (not shown) the range of radioactivity level for the waste which can successfully be handled is increased. The field of view is generally configured to be a slice through that investigating location 5, the slice being substantially parallel to the turntable 13 and/or perpendicular to the axis of the drum 3 under consideration.

For gamma rays the detectors may be of the germanium type, for instance high purity germanium type. LRGS or HRGS detectors may be used, with electrical or LN_2 cooling for HRGS detectors.

The provision of more than one detector, collimated to different fields of view, allows a greater number of measurements to be taken simultaneously, hence increasing the throughput for the system.

The detectors 23 monitor gamma rays originating in their field of view in the drum 3 and in effect generate count rates. A count time of less than 30 minutes is generally employed.

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The signals obtained from the detectors are fed to processing electronics 27 and hence to a CPU 29 and operator display 31. Operator control and inputs are facilitated through keyboard 33.

The processing electronics 27 are provided with error handling functions and diagnostic facilities, as well as providing the appropriate calibration functions.

Processing of the signals gives detailed information on the assay of waste material in the drum 3, the isotopic make-up of the waste. More details of these analyses are discussed below. The results can be used to classify waste according to the relevant disposal categories, including those below a deminimus level which can be characterized as non-radioactive. The results can be expressed the identification of fission products, activation products or MGA code. The results can also be combined with the "fingerprinting" technique to give non-measurable isotope determinations.

The results obtained can be improved using a variety of potential correction techniques. Correction based on weight and/or differential peak adsorption and/or use of a transmission source may be used. In this invention the new correction techniques detailed in the same applicant's UK Patent Applications designated P17453 and/or P17600 also filed on 11 January 1999 may also be used and details of those techniques are fully incorporated herein by reference.

Through the use of a transmission source or sources 35 on transmission side 19 in combination with stepped rotation of the drum 3 tomographic style investigations of the drum can be made to give plots of density distribution and radioactive distribution for the drum 3.

Surface originating alpha and/or beta emissions, most preferably gamma emissions, for the drum 3 can also be measured using optional dosimeters 37. The dosimeters are

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normally provided on the transmission side 19 in proximity
with the surface of the drum 3.

As discussed above three different known correction
techniques may be deployed. The principles and operation
behind each of these is now discussed.

Weight based correction seeks to account for the
attenuating effects of the body of material the sources are
in by a factor based on the body of materials density. The
total mass of the entire body of material is divided by the
total volume of the body of material, more commonly the total
volume of the container for the body, to give an overall
density value for the entire body/container. This single
value is then used in the correction of the detected count to
account for the reduction arising due to attenuation.

Differential peak adsorption based correction again
seeks to account for the attenuation effects of the material,
but through a more direct investigation of attenuation. The
gamma emissions from a source anticipated to be in the body
of material at two characteristic energies are considered.
The ratio of the emissions at one energy to the emissions at
the other energy is known (1:1, for instance, for Co-60)
without attenuating materials, and this base ratio is
compared with the actual ratio measured with the attenuating
effects of the body of material present to give a factor
relating to the attenuating effect and hence allowing
correction.

Transmission source based correction comes in a variety
of forms, but each is generally based on determining
attenuation effects on emissions from within the body of
material by measuring the attenuation on externally sourced
gamma emissions. Emissions at a known energy from the
transmission source are detected after their passage through
the body. The ratio of the detected emissions with the body
of material present is compared with the detected emissions
which would occur without the material. The attenuation is

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corrected for based on this difference. The energy of the transmission source is selected to be close to the energy of the emissions from the sample which need correcting.

The prior art transmission correction based techniques present a number of problems or inaccuracies in practice.

The use of a mono-energetic transmission source, as has been deployed to date, renders the correction technique effective to varying degrees for varying waste or sample materials.

The samples under consideration may contain isotopes which emit at a variety of different energies within the spectrum. The energies can be quite low in some instances and high for other instances or be spread across the substantial part of the spectrum.

The mono-energetic sources used to date have been used to determine a correction factor according to the measured effect of the sample on the detected signal for that source following transmission through the sample. The correction factor has been used in relation to all the detected emissions from the sample itself, irrespective of their energy.

In reality the applicant has established that the information gained at that particular energy (and hence the correction factor calculated) are not appropriate across the full width of the spectrum or even a reasonable part thereof. Once away from energies the same as or close to the energy of the mono-energetic source the correction factor becomes inaccurate. Furthermore, the extent and manner of variation of the effects of the sample vary across the spectrum according to the sample characteristics too and as a consequence are not predictable in advance.

To address the problem the present invention employs a multi-energetic source as the transmission source for sample investigation. The sources used are carefully selected to provide energies spanning the important part of the spectrum

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for a number of commonly encountered waste types. The source
material is exemplified by [152]Eu. The intention is to provide
a series of transmission based investigations which bracket
the emissions from within the sample itself. Thus a more
appropriate correction factor can be calculated for the
sample in question and its actual emission energies as the
deviation of those energies from the energies at which the
transmission effects are actually measured and known are
significantly reduced.

The overall effect of the multi-energy source is that
the correction is more accurate and the likely error is
reduced.

The actual correction is obtained from the measured
transmission coefficients, which at the respective energies
are :-

$$\text{Trans. Coeff.} = \frac{R}{R_o} = \exp(-\mu\rho x)$$

where R is the rate of detected photons, R_o is the rate
of emitted photons from the source, μ is the mass absorption
coefficient, ρ is the matrix density, x is the matrix
thickness.

Measured transmission coefficients for two different
samples with significantly different make-ups, at the various
energies given by [152]Eu, would give rise to significant
variation with energy between the two samples, a variation
which would not be apparent from a single investigation at
using transmission correction based on a single energy.

Between the greater number of actually measured values
provided by the new technique, an extrapolated value can be
used. The greater number and range of the measured values
make this extrapolation more accurate too.

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Over and above this correction technique, which is fully accurate at more points and more accurate at the intervening locations, the present invention offers an optimized technique which makes the correction fully effective at all energies.

As well as addressing the range of energies for which the correction is accurate, the enhanced technique also addresses addition problems with the correction techniques applied in the past, as they only went part way to addressing the variations in sample material. The wastes and other samples which need to be investigated vary significantly between batches of waste and even between individual drums. The waste may be soft waste (approx. $0.1g.cm^{-3}$) or metallic and/or ashes and/or cement containing and/or compacted waste (approx. $2.0g.cm^{-3}$ or even greater). These variations have significant effects, but the present technique accounts for the unknown material composition to a very large part too.

In addition to the measured transmission coefficients obtained as described above, the technique also deploys fitted transmission coefficients.

In this technique the material forming the sample is assumed to be made up of three or more elements in unknown ratios. The transmission coefficient at energy i is the sum of the exponential terms for each of the constituents, i.e. for j terms. The definition is :-

$$T_{nj} = \exp\left(-\sum_{j} q_j u_{ij} \right)$$

where q_j is the effective matrix thickness for material j and μ_{ji} is the mass absorption coefficient for material j at energy I.

Three or materials can be used in the determination, but it is preferred that one low atomic number, one mid atomic number and one high atomic number constituent at least

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be used (i.e. low Z, mid Z and high Z elements). The
elements may be hydrogen (low), aluminum (mid) and iron
(high), for instance. It should be noted that the material
selected need not be a constituent of the sample for the
technique to work.

Using this formula transmission coefficients can be
calculated by varying the q_j values. The variations are
aimed at minimizing the sum of the residuals from a
comparison of the measured and calculated/fitted
coefficients. The fitting may be a linear least squares
approach (matrix solution) or cycling through the possible q
values. Once minimized a set of q_j values are reached which
can be used to calculate accurately the transmission
coefficient at any desired energy I.

In effect the technique assigns a fixed proportion of
each composite material to best describe the unknown
elemental composition of the sample. The result is an
accurate transmission coefficient at any energy and hence
full correction at any energy.

Figure 2 illustrates measured and fitted transmission
coefficients calculated in the above mentioned manner for a
200 litre drum containing a paper matrix (density $<0.1g.cm^{-3}$), whilst Figure 3 illustrates measured and fitted
transmission coefficients for a PVC matrix (density =
$0.4g.cm^{-3}$) and Figure 4 illustrates measured and fitted
transmission coefficients for an iron matrix (density
$1.5g.cm^{-3}$).

This additional correction technique offers accurate
correction over a wide energy range and also avoids the need
for the transmission source to have emission energies which
bracket the energy of the isotope of interest (without loss
of accuracy) as correction can accurately be extrapolated and
compositional assumptions on the sample material are not
needed.

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The techniques described above can be used for a container or drum taken as a whole. However, the technique is adapted to a more accurate and thorough investigation which takes into account likely variations between different parts of the sample.

The technique, improved measured transmission based correction and/or the still more accurate measured and fitted transmission based correction can both be applied to individual slices or other parts of the sample/container by using suitable collimated detector fields of view. In this way density variations in the sample with, for instance height, can be accounted for. Similarly variations in material composition with, for instance height, can be accounted for and partially filled drums can be handled accurately. No assumptions on the compositional make up of the material or its distribution need be made.

The results of the individual parts can be considered separately or in combination to give an overall view point.
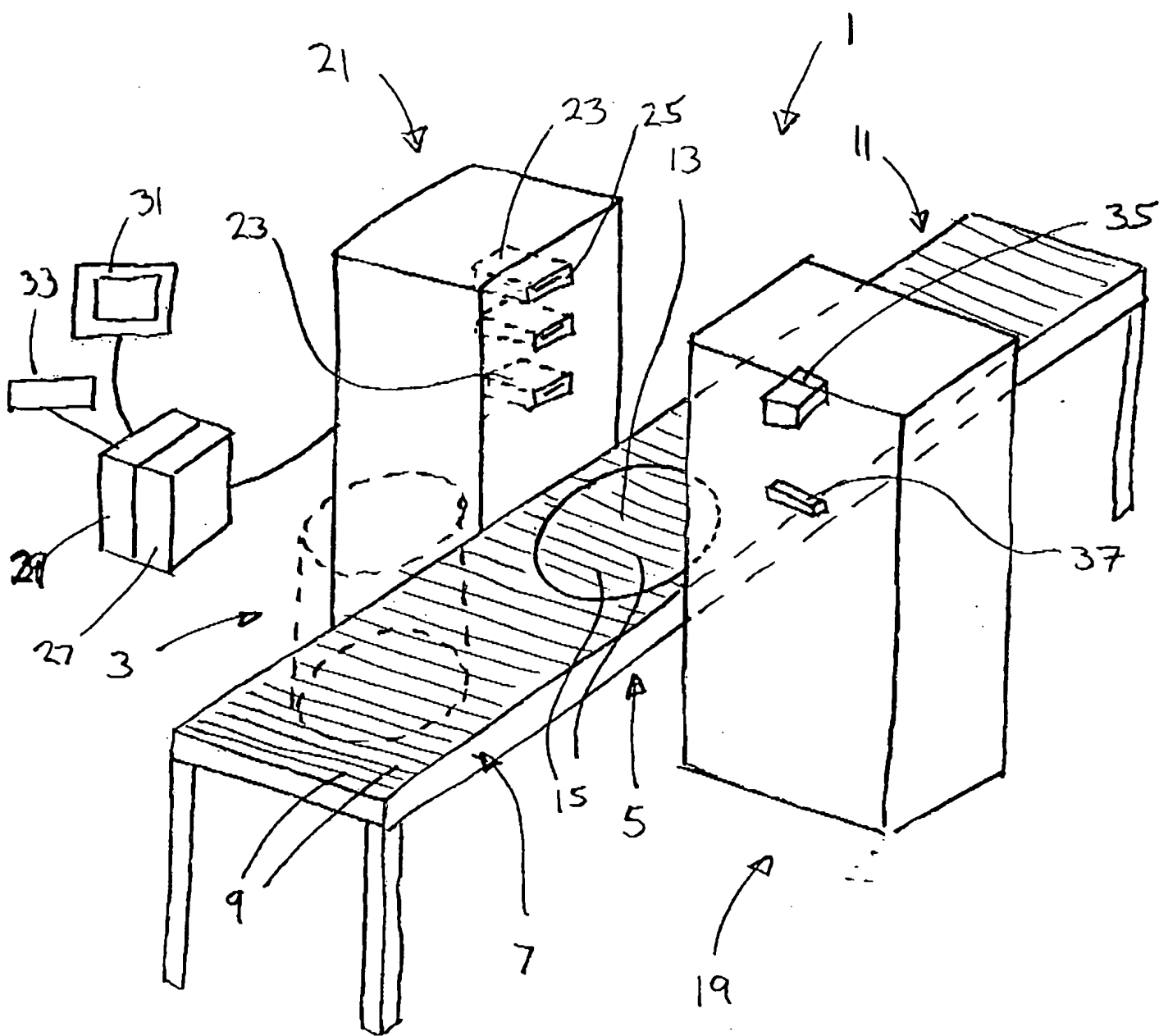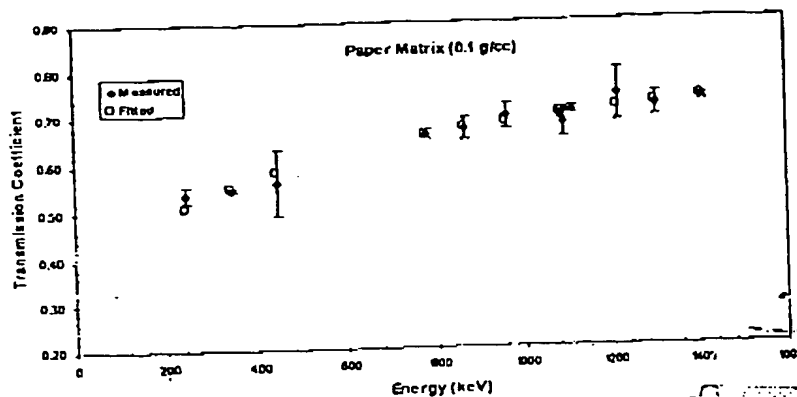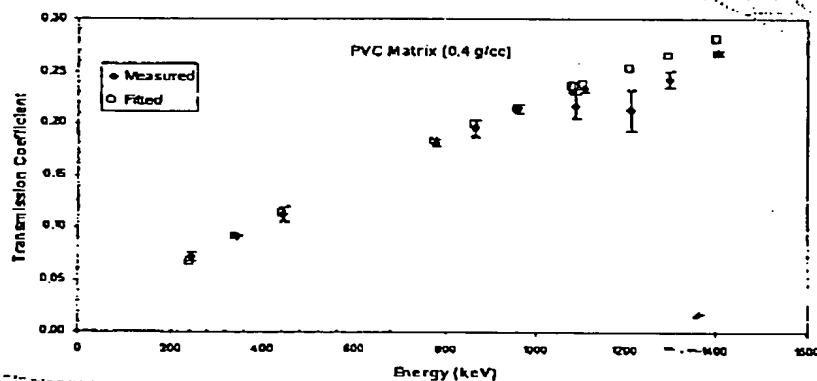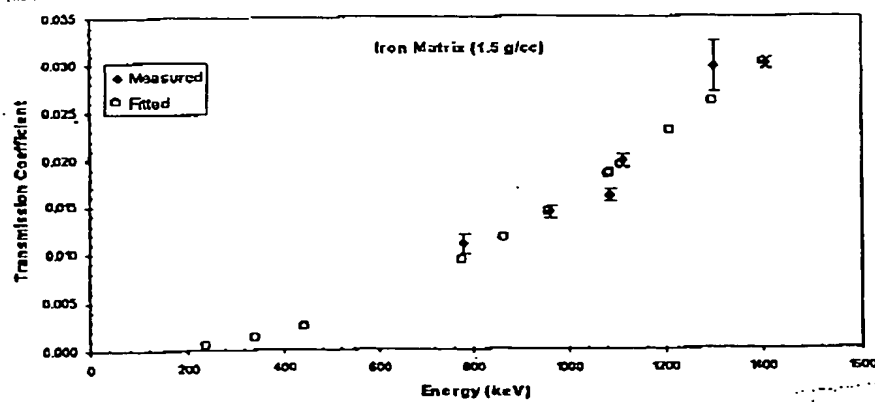
Fig 1

Paper Matrix (0.1 g/cc)

Fig 2

PVC Matrix (0.4 g/cc)

Fig 3

Fig 4

Iron Matrix (1.5 g/cc)